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Assessing Impacts of Operations on Fish Reproduction in Missouri River Reservoirs

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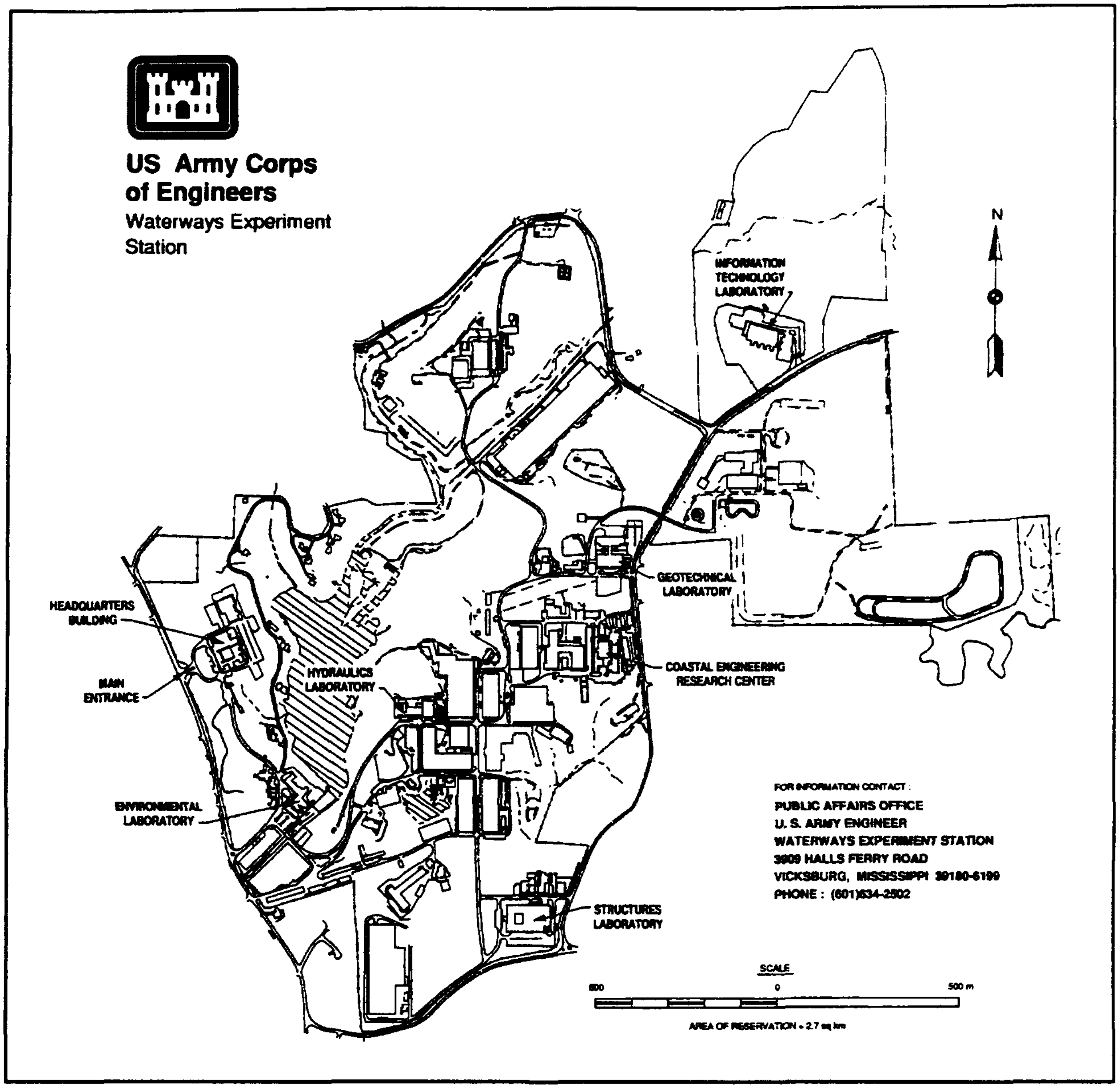

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Preface

This report was prepared by the Water Quality Contaminant Modeling Branch (WQCMG), Environmental Processes and Effects Division (EPED), Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES), for the U.S. Army Engineer Division, Missouri River (MRD), Omaha, NE.

The report was prepared by Messrs. Gene R. Ploskey of WES; Mark C. Harberg of MRD; Greg J. Power of the North Dakota Game and Fish Department; Cliff C. Stone and Dennis G. Unkenholz of the South Dakota Department of Game, Fish, and Parks; and Bill Weidenheft of the Montana Department of Fish, Wildlife, and Parks. The work was conducted under the general supervision of Dr. Mark S. Dortch, Chief, WQCMG; Mr. Donald L. Robey, Chief, EPED; and Dr. John Harrison, Chief, EL.

The Reservoir Fisheries Task Group of the Missouri River Basin Association's Environmental Subcommittee contributed many ideas used to develop the postprocessing method. Ms. Laura Scott, contract student, WES, translated all Statistical Analysis System programs to FORTRAN to make them suitable components in MRD's environmental impact model.

Dr. Robert W. Whalin was Director of WES during the publication of this report. COL Bruce K. Howard, EN, was Commander.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acre-feet	1,233.489	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
hectares	2.471	acres
inches	25.4	millimeters
miles (U.S. statute)	1.609347	kilometers

1 Introduction

Background

The U.S. Army Engineer Division, Missouri River (MRD), controls, maintains, and conserves water resources on the mainstem Missouri River to fulfill project purposes authorized from 1930 through 1940. Since authorization, considerable demographic, social, economic, and political changes have occurred in the region. In 1990, MRD began re-evaluating the *Missouri River Master Water Control Manual* to identify the operating plan that best meets the wide variety of needs in the basin. Impact assessment methods that would allow MRD to identify the effects of different operating plans on basin resources or uses had to be developed. These methods would facilitate trade-off analyses to help MRD identify the operating plans that would provide for the equitable use of resources for authorized purposes (hydropower, flood control, water supply, navigation, water quality, recreation, and fish and wildlife).

Purpose

The authors of this report sought to develop a method for predicting the impacts of system-operating alternatives on fish in the six main stem reservoirs (Fort Peck, Sakakawea, Oahe, Sharpe, Francis Case, and Lewis and Clark) of the upper Missouri River.

Objectives

First, our aim was to use correlation and regression to quantify the effects of seasonal or annual variations in reservoir hydrology on catches of young-of-year (YOY) fish in summer. Second, we hoped to develop software that would quickly calculate a fish reproduction index (RI) for every possible year in the period of record (1898-1990) for any operational

alternative. We wanted the MRD to be able to evaluate operational alternatives by comparing a long chronology of predicted indices and statistics.

2 Methods

Hydrologic Data

We developed quadratic relations to predict reservoir surface area and volume from the surface elevation of the six impoundments (Table 1). These relations were needed because end-of-month data on area and volume were not as readily available as data on elevation, inflow, and release. We wanted to derive independent hydrologic variables from area or volume instead of elevation so that their dimensions would be consistent with area or volumetric dimensions associated with measures of nutrient loading and reservoir productivity. Also, fish catch per unit effort in gears like seines also could be expressed on an areal basis.

Hydrologic data consisting of end-of-month elevations, inflow, release, and subbasin inflow from 1967 to 1990 were provided for every reservoir by the MRD. From these data, we derived 22 hydrologic variables describing annual and seasonal hydrologic characteristics that were believed to be important determinants of YOY fish catch in annual samples taken by State fishery biologists in the basin (Table 2). Plots of standard deviations versus means of all independent variables indicated which variables required transformation to stabilize variances and normalize distributions. We checked normality using the UNIVARIATE procedure (SAS Institute, Inc. 1988a). Many variables were transformed by taking the base 10 logarithm of values plus one. Other transformations such as natural logarithm, reciprocal, and square root were tested but failed to provide significantly better normalization than the base 10 logarithmic transformation. Change-in-area variables were not transformed because we wanted to retain both negative and positive values.

Hydrologic variables derived for each reservoir and select sample statistics are presented in Tables 3-8. We explored conditions unique to individual reservoirs to account for differences in times of fish spawning, which varied with latitude, by using different sets of hydrologic variables. We did not use area variables for Lake Sharpe and Lewis and Clark Lake (Tables 6 and 8) because area does not vary significantly among months. Variables for these riverlike reservoirs were based upon inflow and flushing rate (total release/mean volume).

We also derived independent variables similar to those in Table 2 from daily hydrologic data. Our goal in using daily data was to determine whether similar models would be derived from daily and monthly data and to define potential limitations of using end-of-month data. The source of hydrologic data for evaluating alternative operations, MRD's Long Range Study (LRS) model, provided end-of-month data exclusively. Two variables unique to daily data included maximum change in area and the coefficient of variation (CV) in area from 15 April through 15 May. We hoped to capture negative effects of short-term drops in water levels that might damage fish reproduction by disrupting spawning (June 1970, Vogele 1975, Walburg 1976), exposing eggs (Aass 1960; Heman, Campbell, and Redmond 1969; Priegel 1970; Estes 1971), or concentrating YOY for predators (Bennett 1962, Jenkins 1970, Beard and Snow 1970, Aggus 1979).

Weather Data

Temperature, wind, and storm frequency are believed to be important factors affecting the reproductive success of many reservoir fishes (Walburg 1972, Clady and Hutchinson 1975, Clady 1976, Summerfelt 1975, Nelson and Walburg 1977, Aggus 1979). Wind and waves can increase turbidity and sedimentation along shorelines, and sedimentation adversely affects survival of eggs and YOY fish (Hassler 1970). Weather data recorded hourly from 1973 to 1990 at seven municipal airports along the upper Missouri River were obtained from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce. Sites included Glasgow, MT, for Fork Peck Lake; Williston and Bismarck, ND, for Lake Sakakawea; Bismarck, ND, and Pierre, SD, for Lake Oahe; Pierre, SD, for Lake Sharpe; and Pierre, SD, and Norfolk, NE, for Francis Case and Lewis and Clark Lakes. We used a heat-exchange model to calculate daily equilibrium temperatures from estimates of percent cloud cover, air temperature (wet-bulb, dry-bulb, and dew-point), wind speed, longitude, latitude, and elevation. Equilibrium temperature was used as a surrogate for water temperature, which was rarely available. We derived three independent variables including equilibrium temperature, the frequency of wind speeds exceeding the 75th percentile wind speed, and the number of storm hours from 31 March through 30 June every year, coincidental with fish spawning and nursery periods. A storm hour indicates that a storm was present during some part of an hour monitored by a weather station. Equilibrium temperature was $\log_{10}$-transformed; a square root transform was used on wind-speed and storm-hour variables.

Covariates

We used sport-fish stocking data from Montana, North Dakota, and South Dakota to derive variables for use as covariates in regression analysis. Variables included base 10 logarithmic transformations of one plus the number of fingerling or fry of various species stocked annually.

Intercorrelations

Because of the nature of annual and seasonal hydrologic events, most hydrologic variables exhibited some degree of intercorrelation. When independent variables are correlated, regression coefficients are not unique, but depend on other intercorrelated variables in the model. Nevertheless, correlations between independent variables usually are not a serious problem if the goal is to derive models for inference or to predict new observations (Neter and Wasserman 1974).

Low degrees of intercorrelation were accepted, so we could use as many variables as possible for regression. We used intercorrelated variables when they explained less than 55 percent of the variation in other independent variables ($r < 0.75$; $r^2 < 0.55$, where r = correlation coefficient, r^2 = coefficient of determination). We forced regression models to use only one of several more highly correlated ($r^2 > 0.55$) independent variables. The single intercorrelated variable chosen for regression either explained the most variation in dependent (fish) variables or was the most logical relative to effects documented in the literature.

Dependent Variables

State conservation agencies provided data on the summer catch of YOY fishes in a variety of gears including seines (in Fort Peck; Oahe, SD; Sharpe; Frances Case; and Lewis and Clark), frame nets (Sakakawea and Oahe, ND), and gill nets (Sakakawea; Oahe, ND; and Francis Case). Seines were 100 by 9 ft[1] with 0.25-in. mesh, and frame nets were 3 by 4 ft with 0.25-in. mesh and had a 50-ft-long lead. Gill nets used in Sakakawea and Oahe, ND, were 125 by 6 ft, with 0.5-in. monofilament mesh. Experimental nets used in Francis Case were 300 by 8 ft with six 50-ft panels of 0.5-, 0.75-, 1.0-, 1.25-, 1.5-, and 2.0-in. mesh. Most sampling was in August or September. Data were transformed by taking the base 10 logarithm of one plus catch and averaged to obtain one value per reservoir, gear, species, and year. We assigned a catch of zero for species missing from all samples in a year if it was captured in other years. The YOY

[1] A table of factors for converting non-SI units of measurement to SI units is given on page vi.

catch of walleye in Lake Sakakawea was adjusted so that only data on naturally produced fish were used for regression analysis. The catch of all YOY walleye was multiplied by one minus the fraction that was stocked (number marked/total YOY catch). This adjustment was possible because stocked walleye were intensively marked by the North Dakota Game and Fish Department in a stocking-evaluation project. Catch statistics for YOY fish in all six reservoirs are presented in Table 9.

The catch of YOY fish in summer was used as a dependent variable representing reproductive success for two reasons. First, State resource agencies for Montana, North Dakota, and South Dakota indicated that the relative abundance of YOY fishes is a fairly reliable indicator of future year-class strength in these reservoirs (e.g., Figure 1). Although an abundant cohort of YOY fish may not always survive to create a strong year class (Fourt 1978), the probability is much higher than when few YOY are produced. Second, YOY catch and water-level changes that potentially affect catch are measured in the same year. By contrast, the catch of 2-year-old and older fish, which should more accurately reflect the density of harvestable fish, would have to be lagged 2 to 7 years to match them with hydrologic conditions that may have produced them. Without accurate

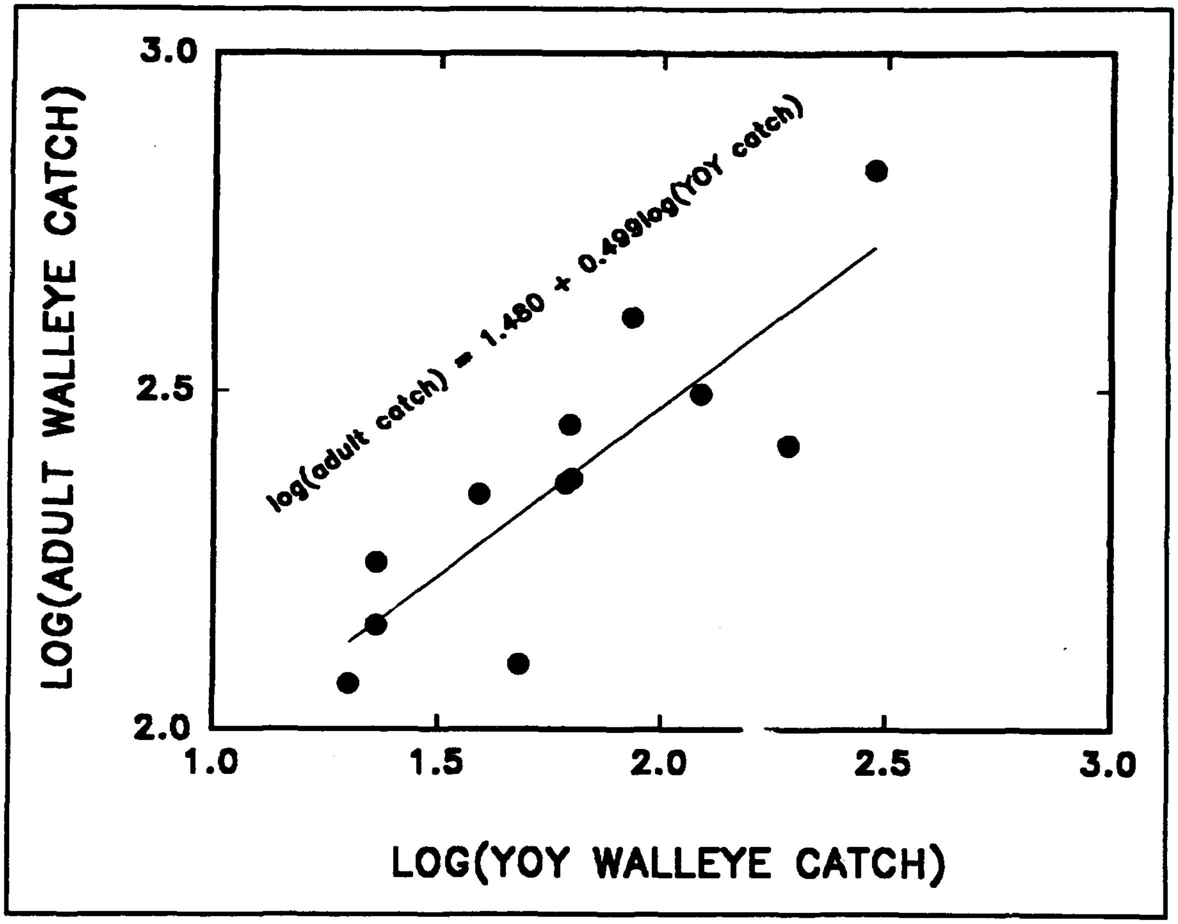

Figure 1. Adult walleye catch as a function of YOY walleye catch in earlier years in Lake Sakakawea (r^2 = 0.71, P = 0.0006)

age and growth data, this lagging process could have an error as large or larger than the one potentially resulting from the assumption that densities of harvestable fish are proportional to YOY densities in earlier years. The catch of older fish also may be affected by factors such as density-dependent growth, natural mortality, and fishing mortality that can obscure first-year effects of water levels.

Correlation and Regression Analyses

Correlation and multiple-regression analyses were used to find the best combinations of hydrologic variables for predicting YOY catch from historic data. Dependent catch variables were matched by reservoir and year with hydrologic, weather, and covariate stocking variables. We generated Pearson product-moment correlation matrices with the CORR Procedure and regression models with the REG Procedure (MAXR option) of the Statistical Analysis System (SAS Institute Inc. 1988a and b). Regression equations were evaluated based upon statistics such as the significance level of the model and parameter estimates, the change in mean square error as new variables were added, and the coefficient of determination (r^2 or R^2). We did not accept multiple-regression models if the relation of YOY catch to an independent variable differed (positive or negative) from what was observed in correlation analysis. Most importantly, equations had to be biologically realistic compared with known ecological mechanisms.

Results of two rounds of correlation and regression analyses were presented to the Reservoir Fisheries Task Group. After the first round of analyses, we selected regression equations meeting the criteria described in the previous paragraph. Next, we picked several indicator species for each reservoir from among the species with significant relations to hydrologic variables. Indicator species were selected because they were important to the fishery, were highly affected by operations, or represented a distinct spawning strategy (e.g. riverine, pelagic, nesting, or broadcast on vegetation). Significant relations were not obtained for fish representing every spawning strategy. A list of equations was presented to all data contributors for concurrence on the best equations to use in predictive software.

Postprocessing

Background

We had to reduce multi-reservoir, -gear, and -species predictions into indicators of impacts of operational alternatives on fish reproduction for the entire system of reservoirs for the period of record. The MRD needed this data-reduction process to develop a method to quickly evaluate hundreds of possible operating alternatives. We had to combine predictions for six reservoirs, three sampling gears, and from two to five species per reservoir. The researchers made and compared predictions (by reservoir, gear, and species) for four distinctly different operational alternatives.

The integrated model uses hydrologic output of MRD's LRS model to calculate annual values of RI (reproductive index from 1900 to 1990). The RI is considered the best available index for impact assessment because models were based upon empirical catch data for several species of fish.

Reproductive Index

The RI was calculated in a five-step process. First, we made predictions of YOY catch by reservoir, gear, species, and year (1900-1990). Second, we standardized predictions by dividing predicted catch by the maximum observed catch for the same species, gear, and reservoir, despite the alternative, so each species was weighted equally. Third, standardized predictions were weighted by gear-specific factors and area of habitat to produce an index to the total number of YOY fish of each species by reservoir, gear, and year. Standardized seine catches were divided by 0.073, i.e., hectares sampled in a single quarter or 90-deg-arc haul and multiplied by the mean area overlying depths of 0 to 30 ft (assumed depths of YOY habitat) for 1 to 2 months of summer. Months included June and July (Francis Case and Lewis and Clark Lakes), July (Lake Sharpe), July and August (Lake Oahe), and August and September (Sakakawea and Fort Peck Lakes). Standardized gill- and frame-net catches were divided by 0.1 (assuming each net sampled 0.1 ha) and multiplied by area over 0- to 30-ft depths in the months listed above. Fourth, we summed standardized indices by reservoir and year, combining different gears and species. Fifth, we standardized the 93 annual RI values by reservoir by dividing each by the largest RI observed for that reservoir under any alternative, so each reservoir was weighted equally. These standardized indices were summed by year to index fish reproduction for the entire six-reservoir system. The weighting of YOY catch by habitat area in each reservoir in the third step and differences in the number of species per reservoir forced us to standardize by reservoir a second time in the fifth step.

We weighted predictions by reservoir area overlying depths of 0 to 30 ft to account for differences in resource size among alternatives that resulted from different pool levels. Predicted geometric mean catch is an indicator of fish density, not of the total number of fish. Total number is related to density and surface area. For example, a reservoir with low-pool elevations during drought may have the same density (number per unit area) of YOY fish as it does when the basin is full. However, the total number of YOY present would be higher at full pool because there is more area supporting YOY fish.

Our assumption that gill and frame nets sample 0.1 ha may not be accurate, but 0.1 is a constant applied to all gill- and frame-net predictions, despite the operational alternative evaluated. Therefore, the procedure is no different from weighting catch by surface area overlying depths of 0 to 30 ft. The area sampled by a passive gear varies greatly because of factors affecting fish activity and movement. Our use of a constant sample area was more to show that the quantity was unknown than to assign an average value.

3 Results

Area- and Volume-Elevation Relations

Quadratic area- and volume-elevation relations (Table 1) were useful for estimating area and volume from elevation data recorded from 1976 to 1988. Coefficients of determination (R^2) for all quadratic equations exceeded 0.99. These equations would be less accurate for data collected before 1976 or after 1988 because of sedimentation, which affects area and capacity at different elevations. Quadratic area-elevation equations were better predictors of surface area than the first derivative of the elevation-volume equations, which are sometimes used to derive area estimates.

Effects of Stocking

Small sample sizes and poor correlations between YOY fish catch and most stocking variables kept us from using stocking variables as covariates in regression analyses. In this study, stocking variables limited the number of years that could be included in a model and reduced most sample sizes to five or less. Stocking records seldom provided more than 5 years of data for any species. The sample size of a multiple-regression model is determined by the number of observations in which every independent variable has a nonmissing value. Observations that include a missing value for any independent variable in a model are dropped from the analysis.

Correlations showed that fingerling walleye stocking is a legitimate covariate, although sample sizes were small. We found positive correlations of YOY walleye catch with stocking variables for walleye fingerlings (but not fry) in Fort Peck Lake ($r = 0.54$, $P = 0.1348$, $N = 8$), Lake Sakakawea ($r = 0.76$, $P = 0.0304$, $N = 8$), and Lake Oahe, SD ($r = 0.62$, $P = 0.0953$, $N = 8$). Insufficient data were available to look for correlations between YOY walleye catch and stocking in Lake Sharpe, Lake Francis Case, or Lewis and Clark Lake.

Results suggest that predictions of YOY catch could be significantly improved by accounting for stocking variation, either by using stocking as a covariate (sample sizes permitting) or by adjusting catch data when stocked fish were marked. Our adjustment of YOY walleye catch in Lake Sakakawea to include only nonstocked YOY resulted in a stronger relation between YOY catch and change in area from April through June than when catch consisted of both stocked and naturally produced walleye. Change in area from April through June was the most important determinant in both cases, but eliminating stocking effects increased the equation's r^2 from 0.25 to 0.58 and reduced its probability from 0.0295 to 0.0002. Most years of sport-fish stocking by resource agencies occurred during the drought of the 1980's, which probably increased apparent reproductive success, as indicated by catches of YOY sport fishes.

Effects of Weather

Correlation of YOY catch with weather variables yielded few consistent or useful results, and weather variables were not included in regression analyses. We found positive correlations of storm hours from April through June with the catch of YOY white bass in Lake Oahe, SD ($r = 0.47$, $P = 0.0365$, $N = 20$), and Lake Sharpe ($r = 0.7826$, $P = 0.0001$, $N = 18$) and with the catch of YOY yellow perch in Lake Francis Case ($r = 0.58$, $P = 0.0467$, $N = 12$). By contrast, storm hours from April though June were negatively correlated with catches of YOY sauger ($r = -0.52$, $P = 0.0285$, $N = 18$) and gizzard shad ($r = -0.41$, $P = 0.0939$, $N = 18$) in Lewis and Clark Lake. The 75th-percentile wind speed from April through June was positively correlated with YOY catches of white bass ($r = 0.58$, $P = 0.0996$, $N = 9$), white crappie ($r = 0.61$, $P = 0.0844$, $N = 9$), and yellow perch ($r = 0.43$, $P = 0.0575$, $N = 20$) in Lake Oahe, SD, and walleye ($r = 0.55$, $P = 0.0968$, $N = 10$) in Lake Francis Case, and gizzard shad ($r = 0.58$, $P = 0.0114$, $N = 18$) and sauger ($r = 0.41$, $P = 0.0891$, $N = 18$) in Lewis and Clark Lake. White crappie in Lake Sharpe were inversely correlated with the 75th-percentile wind speed ($r = -0.67$, $P = 0.0476$, $N = 9$). The only two correlations of mean equilibrium temperature from April through June with YOY catches had opposite trends, one positive (Lake Oahe yellow perch ($r = -0.48$, $P = 0.0298$, $N = 20$)) and the other negative (Lake Sharpe white crappie ($r = 0.73$, $P = 0.0266$, $N = 9$)).

We thought that storm hours during spawning would be inversely related to reproductive success of many species because wind-induced turbulence could disrupt spawning, strand eggs and larvae along shorelines, or increase silt deposition and mortality of nonpelagic eggs. Surprisingly, three of the five correlations we found were positive. Localized storm events could increase nutrient loadings from the immediate watershed and thereby increase primary and secondary production and therefore YOY survival. Catches of YOY white bass were positively correlated with subbasin inflow in Lake Oahe. Adult white bass spawn in tributaries.

However, we believe more species would be affected if productivity were the underlying cause. Also, 3 significant correlations out of 26 possible correlations of YOY catch with storm hours are not much above the level of chance (0.05). The two negative correlations with storm hours obtained for two species in Lewis and Clark Lake seem to support our original hypothesis about negative effects. However, storms are less likely to be a problem for fish in a narrow impoundment like Lewis and Clark Lake than they would be in a reservoir with a large "fetch," i.e. distance over which wind can blow uninterrupted by land (e.g. Fort Peck, Sakakawea, Oahe, and Francis Case). Negative correlations of storm hours with YOY gizzard shad and sauger catches could be related to high turbidity introduced to Lewis and Clark Lake by the Niobrara River during the spawning season. Catches of YOY sauger and gizzard shad also were inversely related to subbasin inflow.

The importance of weather at one or two sites near a reservoir to fish reproduction throughout the same reservoir may be questionable, because weather can be highly localized. At best, data from such weather stations might realistically portray effects of widespread fronts. However, they also would record local episodic events that did not occur 30 to 100 miles away and would miss similar events on other areas of a lake, especially large lakes like Fort Peck Lake, Lake Sakakawea, and Lake Oahe. This might explain the six positive correlations of the frequency of winds exceeding the 75th-percentile wind speed with catches of YOY fishes. The only negative relation was obtained for white crappie in Lake Sharpe, a mainstream reservoir with little fetch. Documented effects of wind on fish reproduction have been exclusively negative (Clady and Hutchinson 1975, Summerfelt 1975, Clady 1976, Aggus 1979). The best and perhaps only way to document effects of weather would be to continuously monitor weather at multiple fish-sampling sites.

Daily Versus Monthly Hydrologic Data

Correlation and regression analyses using hydrologic variables derived from daily data provided little or no improvement in predictive capability over variables derived from monthly data. The same hydrologic variables usually were significant or nonsignificant despite the time-step, probably because all data were reduced to one number per year to match with fishery data. Maximum change and the CV in area from 15 April through 15 May were variables that could be calculated only from daily data. Our hypothesis was that these variables would explain variation in YOY catch because of negative impacts of drops in water level during spawning. However, both variables were positively correlated with spring increases in area and with the catch of several YOY fishes the next August. Either these variables do not capture effects of brief (1 to 2 day) episodic drops in water level during spawning, or such sporadic events do not affect YOY fish production as much as other factors that occur after spawning (Gassaway 1970).

Regression Analyses

We found many highly significant relations by regressing the geometric mean catch of YOY fishes on hydrologic variables derived from monthly data. Equations retained for development of predictive software (Table 10) survived careful scrutiny to eliminate relations that could not be explained by mechanisms documented in the literature. For example, years of very high inflow are associated with greater surface area absorbing solar insolation, increased inundation of terrestrial areas, high nutrient loading (Perrier, Westerdahl, and Nix 1977; Westerdahl et al. 1981), and increased primary and secondary production (Benson and Cowell 1967, Dussart et al. 1972, Vollenweider 1975, Ostrofsky and Duthie 1978, McCammon and von Geldern 1979, Grimard and Jones 1982). When vegetation in the fluctuation zone is flooded, some fishes are afforded optimum spawning and nursery habitat, e.g. yellow perch (Beckman and Elrod 1971), northern pike (Benson 1968, Hassler 1970), buffaloes (Moen 1974), and common carp (Gabel 1974), that enhance their survival (Martin et al. 1981). The literature on effects of water levels and inundation of vegetation is replete with references to above-average reproduction and the development of strong year classes of fish under such conditions (Benson 1968; Beckman and Elrod 1971; Nelson and Walburg 1977; Nelson 1978; Ploskey, Aggus, and Nestler 1985; Ploskey 1986). Regression equations for indicator species in Fort Peck Lake, Lake Sakakawea, Lake Oahe, and Lake Francis Case (Table 9) are typical of positive responses to above-average inflow and water levels. Densities of these YOY fish usually were highest in high-water years, in spite of substantial dilution by increased water volume.

Multivariable models sometimes contain seasonal inflow or change-in-area variables with negative coefficients, but usually other hydrologic variables in the model had more effect on the cumulative response. Effects of change-in-area variables cannot be interpreted solely by noting signs of coefficients. Equations with positive coefficients but typically negative values indicate that small decreases in area are more beneficial than large ones. Conversely, equations with negative coefficients for variables with typically negative values indicate that large decreases in area would be better for fish reproduction than small decreases.

We know that YOY fish can be physically concentrated by greatly reduced water levels or flushed from run-of-river impoundments. These mechanisms can obscure or override our ability to see true increases in YOY fish densities that might result from increased system productivity. Equations for fish in the two run-of-the-river reservoirs (Sharpe and Lewis and Clark Lakes) probably reflect greater physical flushing of YOY fish in wet years (Walburg 1971), as relations of YOY catch to inflow and flushing rate variables were consistently negative.

In the three largest reservoirs, predicted catches were positively related to flushing rate at normal-pool elevations but inversely related to it at low-pool elevations. Flushing rate (discharge/volume) increases greatly when reservoir volume becomes very low because it is a ratio. We reran regressions after excluding seasonal flushing rate variables for Fort Peck Lake, Lake Sakakawea, Lake Oahe, and Lake Francis Case. We substituted seasonal inflow for flushing rate. We observed consistent positive relations between predicted catches and inflow at all pool elevations. We also dropped equations based solely on inflow variables for Fort Peck Lake because inflow to Fork Peck does not vary with system operations nor among alternatives.

Integrated Model Application to Operating Alternatives

Four system-operating alternatives explored in this study differed mainly in system storage for the four largest reservoirs and inflows to the two run-of-the-river reservoirs during drought (Figure 2). Two alternatives differed very little in seasonal water-level or hydrologic patterns in most years, so impacts to fish reproduction were most obvious in drought years and predicted indices rarely were > 3.0 (Figure 3). A second pair of operating alternatives allowed for significant variation in seasonal hydrologic patterns in many years. These alternatives, which provided a year of high water to one of the three largest reservoirs on a rotating basis, produced similar reproductive indices in most years. However, the alternative allowing the greatest summer drawdown produced six exceptionally high RI values (> 3.0; Figure 4). It also yielded more years with above-average indices (19 years with indices > 2) than the alternative which limited drawdown (13 indices > 2). These results are significant because a strong year class of fish may persist for about 5 to 8 years, and a strong year class of sport fish may dominate catches of anglers for 3 to 5 years. However, the limited-drawdown alternative had 7 years with average indices that exceeded indices of the large-drawdown alternative from 1930 to 1945, a period of drought. Indices for both alternatives were similar in 6 of the 15 drought years, and the large-drawdown alternative produced higher indices than the limited-drawdown alternative in two of these years.

The exceptionally high RI predicted in some years for the large-drawdown, environmental alternative (Figure 4) resulted from wet years coinciding with refill that followed a drawdown year in Lake Oahe. Changes in pool elevations that yielded significant differences in the RI under large-drawdown and limited-drawdown alternatives took place over 2 years. Exceptionally high indices predicted for 1914, 1929, 1971, and 1986 under the large-drawdown alternative were not predicted for the limited-drawdown alternative (Figure 4), because the extent of drawdown in the previous year was much less under the limited drawdown alternative (Figures 5 and 6).

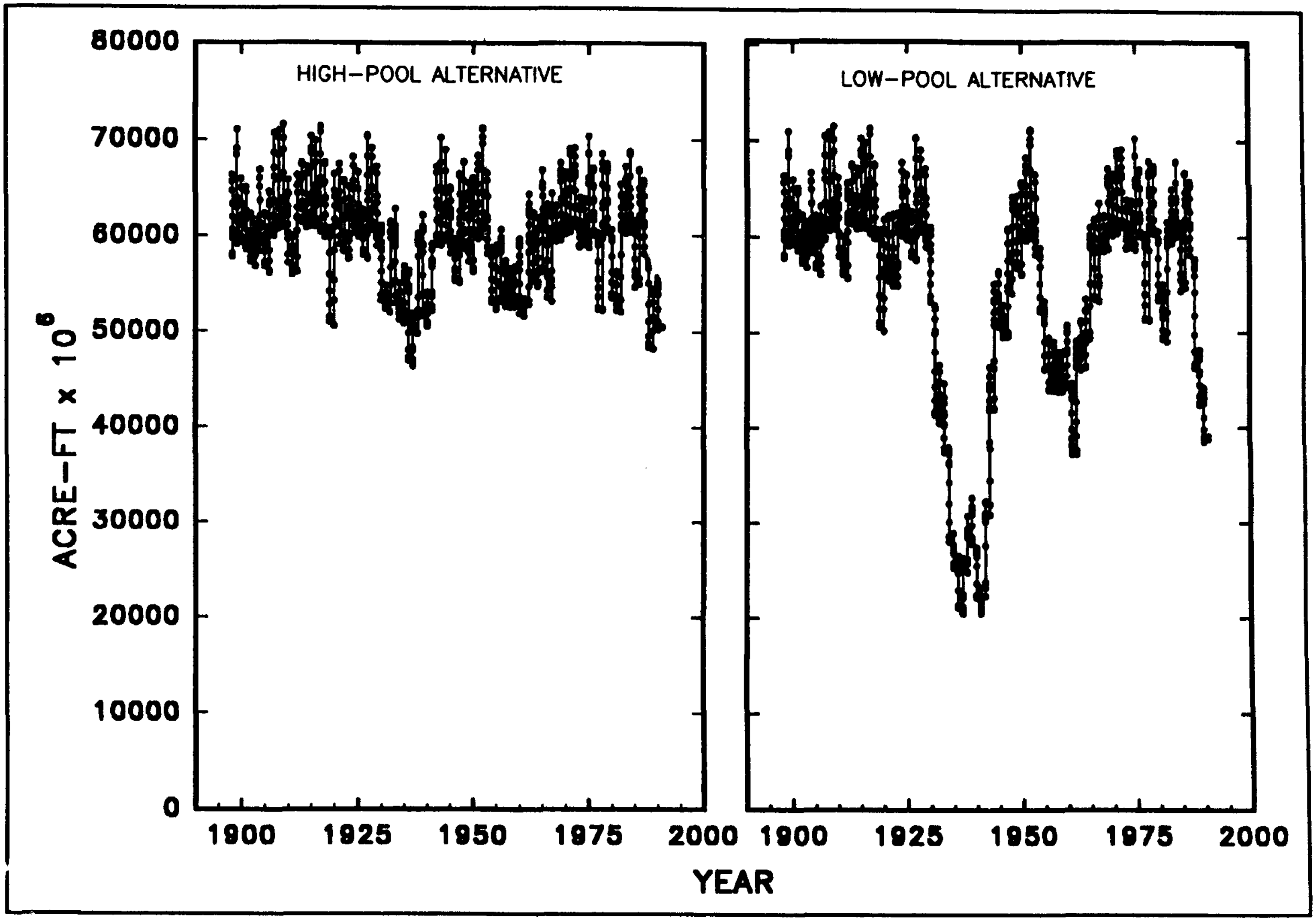

Figure 2. System storage in all Missouri River reservoirs predicted by MRD's LRS Model under two operational alternatives

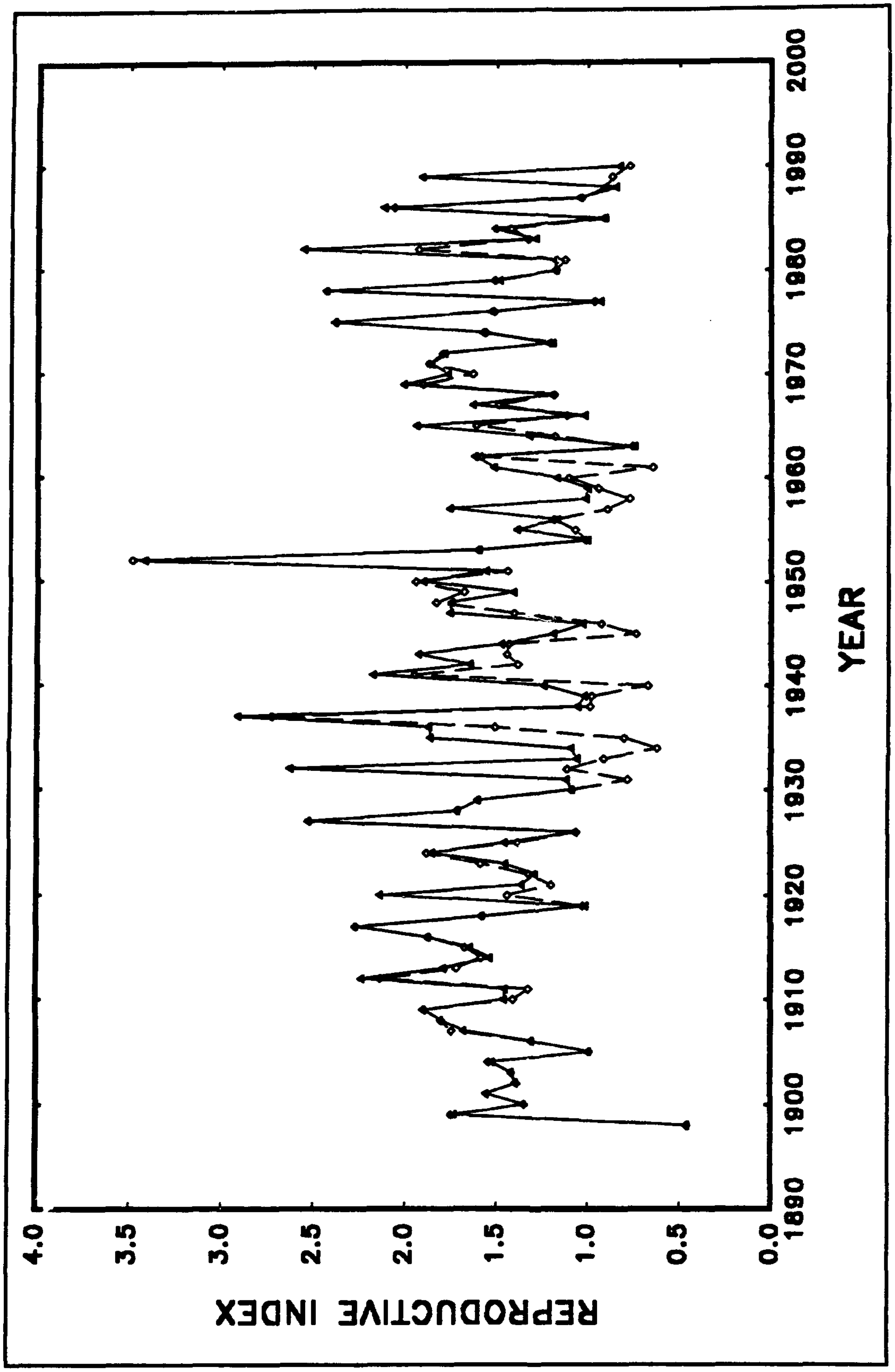

Figure 3. Predicted indices of fish reproduction for six Missouri River reservoirs under high-pool (triangles and solid line) and low-pool (diamonds and dashed line) operational alternatives with similar seasonal hydrologic patterns

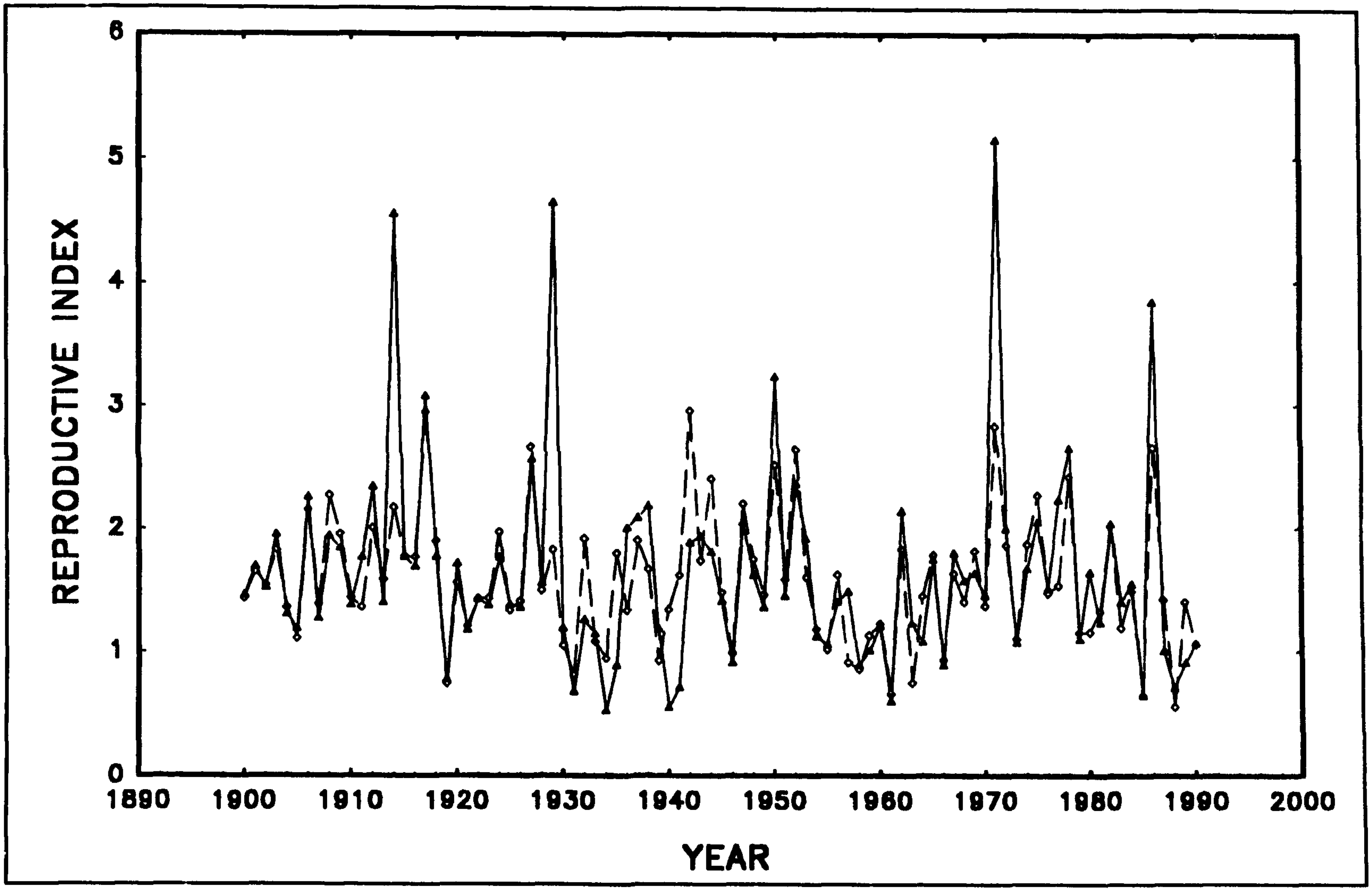

Figure 4. Predicted indices of fish reproduction for six Missouri River reservoirs under large-seasonal-drawdown (triangles and solid line) and limited-seasonal-drawdown (diamonds and dashes) alternatives

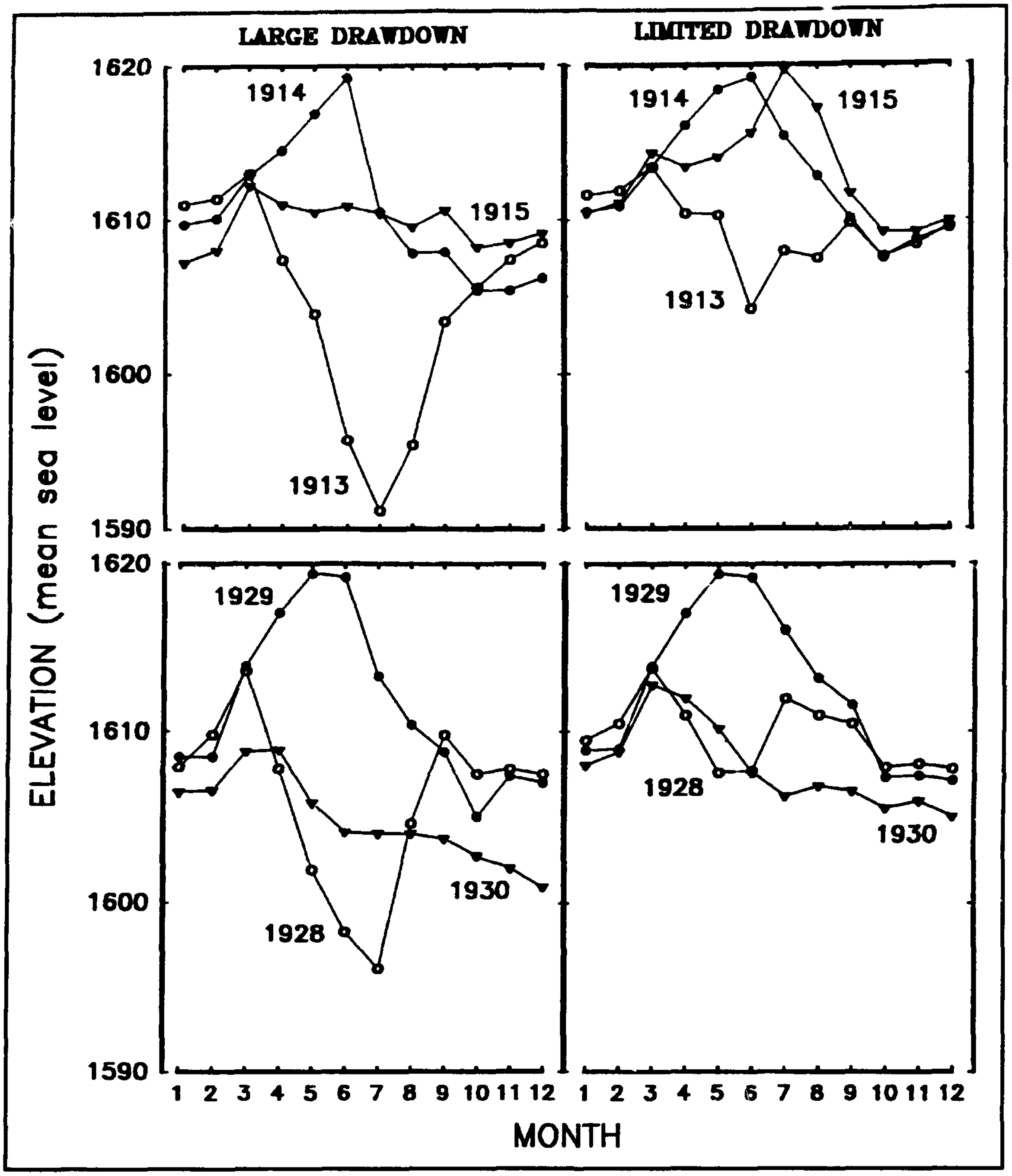

Figure 5. Lake Oahe water elevations under large- and limited-drawdown operational alternatives. The large-drawdown alternative produced exceptionally high fish reproductive indices in 1914 and 1929 in contrast to the average indices generated by the limited-drawdown alternative

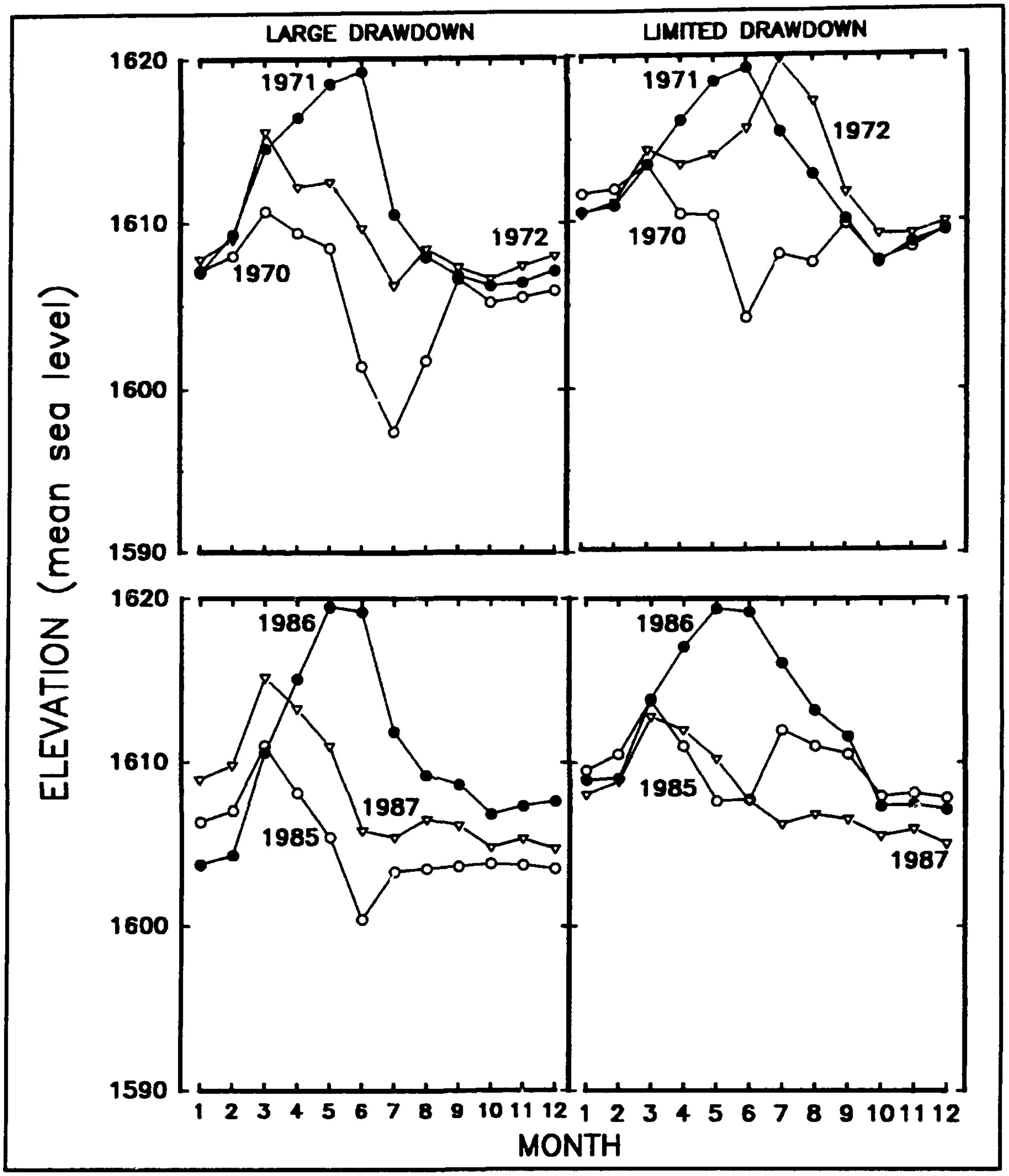

Figure 6. Lake Oahe water elevations under large- and limited-drawdown operational alternatives. The large-drawdown alternative produced exceptionally high fish reproductive indices in 1971 and 1986 in contrast to the average indices generated by the limited-drawdown alternative

Using Individual Regression Models

Single equations (Table 10) can be used to forecast the YOY catch of select species of fish from hydrologic variables (Table 2) derived from monthly elevation, inflow, and release data. End-of-month data can be obtained from MRD or U.S. Geological Survey Surface Water Records. Three steps are required to make predictions. First, obtain or create end-of-month data on elevation, inflow, and release for the year to be predicted and the previous year for a specific reservoir. Second, select equations for the reservoir and species of interest (Table 10); list independent variables used in the equations, and obtain definitions of independent variables (Table 2). Third, calculate values of independent variables according to the definitions; substitute calculated values in the appropriate regression equation, and solve the equation for YOY catch. See Chapter 4, Conclusions and Limitations, for information on predictions using values of independent variables that are outside the range of empirical values used to derive the equations.

Regression equations in Table 10 predict the base 10 logarithm of YOY catch + 1, which can be converted to the geometric or arithmetic mean (Ricker 1975). The geometric mean ($10^{\log(\text{catch})} - 1$) can be converted to an approximate arithmetic mean using the following formula:

$$\log_{10}(AM) = 1.1518\underline{s}^2 (\underline{N} - 1)/\underline{N} + \log_{10}(GM)$$

where AM is the arithmetic mean, GM is the geometric mean, $\underline{N}$ is sample size, and $\underline{s}$ is the standard deviation of the normally distributed base 10 logarithms of catch (Table 9).

4 Conclusions and Limitations

Models can be used to evaluate seasonal operating alternatives or differences in system-operating alternatives (after postprocessing of predictions), as described in previous sections.

Our evaluation of four system-operating alternatives suggests that provision of a year of high water to one of the three largest reservoirs on a rotating basis yields the greatest benefit to natural fish reproduction for the system. Alternatives that limit annual drawdown are desirable only for severe drought periods when the fish reproduction and reservoir fisheries are both adversely affected by low water. In normal water years, large summer drawdown followed by a year of above-average water levels can greatly increase fish reproductive success.

Software developed in this study allows users to make annual or multiyear predictions quickly, but the present version does not screen values of independent variables to make certain they are within the range of empirical data used to derive the regression equations. Extrapolation is a concern primarily for users making predictions of YOY catch with individual equations. In these cases, input data should be screened, or users must assume that relations are consistent over a wider range of values of independent variables than ever observed. Concern over extrapolation should partly depend on how far a value is out of range. For example, values over 100 percent out of range might be considered risky, whereas those 1, 10, 20, or even 30 percent out of range may be believable. Users making predictions with equations in Table 10 should compare calculated values of independent variables to the maxima and minima listed in Tables 3 to 8 to identify years when predictions may be suspect. Users could assign the minimum or maximum (Tables 3 to 8) to an outlying value to assure that predictions are within the original range of values.

Extrapolation beyond the original data is not a serious problem for the integrated model that uses 93 years of predicted hydrology, because YOY predictions are standardized by reservoir and species to values between zero and one. Consequently, a prediction from a single equation cannot overly bias the composite, annual estimate of the RI. In addition, the

model is used solely to compare alternatives, not to make quantitative predictions. Users evaluating system alternatives with 93 years of predicted hydrology, including the extreme drought of the 1930's and the wettest years recorded, likely will be beyond the range of the original data in some years. The environmental alternative that sought to provide high pools in one of the three largest reservoirs every third year and allowed a large seasonal drawdown had the most outliers (Table 11). Variables indexing inflow, flushing rate, or change in area in spring were the most common offenders.

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Table 1
Coefficients in quadratic relations between surface area (acres) or volume (acre-ft) and elevation (ft, mean sea level) in six mainstream Missouri River Reservoirs[1]

Lake	A0	A1	A2	V0	V1	V2
FP	17443774.5664	-17355.6704	4.3158	2522694031.9262	-2433787.8982	586.9796
SA	27276713.1370	-32890.2021	9.9136	2987074723.5567	-3507845.2698	1029.7744
OA	23067376.9553	-31945.4198	11.0682	1984028986.0292	-2710709.6077	925.9710
SH	10478680.7020	-15883.9167	6.0172	725648789.2619	-1071504.7708	395.5526
FC	4571151.6347	-7984.9174	3.4485	653173916.9068	-1036342.2346	411.1322
LC	17935605.2458	-30853.2061	13.2697	637158493.1287	-1083328.8038	460.4746

[1] Equations have the form: $AREA = A0 + A1(ELEV) + A2(ELEV)^2$ or $VOL = V0 + V1(ELEV) + V2(ELEV)^2$, where A0, A1, A2, V0, V1, and V2 are coefficients tabled above, ELEV is elevation, and VOL is volume. Lake abbreviations are as follows: FP = Fort Peck; SA = Sakakawea; OA = Oahe; SH = Sharpe; FC = Francis Case; and LC = Lewis and Clark.

Table 2
Independent hydrologic variables, definitions, and transformations

Type	Variable	Definition	Transformation
Annual or Multi-Year	MG_WY	Mean discharge at an upstream gage (inflow) per year in cms	- $\log_{10}$
	CASUSP	Change in mean area (± ha) summer to spring, i.e., mean of areas at the end of Apr, May, and Jun minus the mean of areas at the end of Jun, Jul, Aug, and Sep in the previous year	- none
	CASUSP2	Sum of changes in mean area (± ha) from summer to spring for two consecutive years (see CASUSP above)	- none
	CASUSU	Change in mean area (± ha) from summer to summer, i.e., mean of areas at the end of Jun, Jul, Aug, and Sep minus the mean of areas at the end of Jun, Jul, Aug, & Sep in the previous year	- none
	CASUSU2	Sum of changes in mean area (± ha) from summer to summer for two consecutive years	- none
Spring	INFV4_5	Total inflow volume (millions of cubic meters) from 31 Mar through 31 May	- $\log_{10}$
	INFV4_6	Total inflow volume (millions of cubic meters) from 31 Mar through 30 Jun	- $\log_{10}$
	XSBINF4_6	Mean of subbasin inflows on 31 Mar, 30 Apr, 31 May, and 30 Jun (cms)	- $\log_{10}$
	XPA4_5	Area (ha) associated with the mean of elevations on 31 Mar, 30 Apr, and 31 May minus area at an elevation 30 ft below the mean	- $\log_{10}$
	XPA4_6	Area (ha) associated with the mean of elevations on 31 Mar, 30 Apr, 31 May, and 30 Jun minus area at an elevation 30 ft below the mean	- $\log_{10}$
	X20V4_6	Volume (millions of cubic meters) associated with the mean of elevations on 31 Mar, 30 Apr, 31 May, and 30 Jun minus volume at an elevation 30 ft below the mean	- $\log_{10}$
	CA4_5	Change in area (± ha): 31 Mar to 31 May	- none
	CA4_6	Change in area (± ha): 31 Mar to 30 Jun	- none
	FR4_5	Flushing rate from Apr through May, where flushing rate is the total release divided by mean volume	- $\log_{10}$
	FR4_6	Flushing rate from Apr through Jun, where flushing rate is the total released divided by mean volume	- $\log_{10}$
Summer	INFV6_9	Total inflow volume (millions of cubic meters) from 31 May through 30 Sep	- $\log_{10}$
	XPA7_11	Area (ha) associated with the mean of elevations on 31 May, 30 Jun, 31 Jul, 31 Aug, 30 Sep, 31 Oct, and 30 Nov minus area at an elevation 30 ft below the mean	- $\log_{10}$
	XPA50_6_9	Area (ha) associated with the mean of elevations on 31 May, 30 Jun, 31 Jul, 31 Aug, and 30 Sep minus area at an elevation 50 ft below the mean	- $\log_{10}$
	CA6_9	Change in area (± ha): 31 May through 30 Sep	- none
	CA7_11	Change in area (± ha): 30 Jun through 30 Nov	- none
	FR6_9	Flushing rate from Jun through Sep, where flushing rate is the total release divided by mean volume	- $\log_{10}$

Table 3
Sample sizes (N), minima, lower quartiles, medians, means, upper quartiles, and maxima of hydrologic variables derived for Lake Fork Peck, Montana

Variable[1]	N	Minimum	Lower Quartile	Median	Mean	Upper Quartile	Maximum
MG_WY	20	158.30	224.21	320.59	295.61	358.83	528.00
CASUSP	19	-8063.00	-5840.00	-216.00	-2742.92	-629.00	2765.00
CASUSP2	18	-12819.00	-10212.00	-5454.50	-5345.78	-2417.00	2095.00
CASUSU	19	-9359.00	-5168.00	-702.00	-1103.68	2400.00	9062.00
CASUSU2	18	-11878.00	-5926.00	-3421.00	-2048.33	3421.00	8217.00
INFV4_6	20	1932.00	2999.99	4258.00	4212.48	5920.97	8217.00
XSBINF4_6	20	0.00	8.78	22.23	17.24	51.96	80.20
XPA4_6	20	13501.99	14814.05	15147.51	15006.07	15276.98	15734.01
CA4_6	20	-1566.00	1823.50	3323.50	3547.00	4666.50	13250.00
INFV6_9	20	2074.00	3190.38	4919.23	4509.04	6195.85	10704.99
XPA6_9	20	13568.00	14968.97	15250.48	15147.72	15512.51	15861.99
CA6_9	20	14716.00	-1221.50	1079.00	889.55	3376.00	7029.00

[1] Variable abbreviations are defined in Table 2.

Table 4
Sample sizes (N), minima, lower quartiles, medians, means, upper quartiles, and maxima of hydrologic variables derived for Lake Sakakawea, North Dakota

Variable[1]	N	Minimum	Lower Quartile	Median	Mean	Upper Quartile	Maximum
MG_WY	24	387.00	560,85	725.93	674.54	820.02	1018.20
CASUSP	23	-15103.00	-10474.00	-6107.00	-6388.26	-1941.00	189.00
CASUSP2	22	-24738.00	-15151.00	-13920.00	-12692.50	-6292.00	-585.00
CASUSU	23	-17808.00	-6840.00	-1090.00	-1347.30	3934.00	13318.00
CASUSU2	22	-24648.00	-10224.00	-59.50	-2593.05	4200.00	14395.00
INFV4_6	24	5581.00	7309.40	9673.96	9553.90	12800.03	14778.99
XSBINF4_6	24	324.70	482.35	635.00	631.48	870.09	1175.50
XPA4_6	24	24234.00	26668.94	27352.95	27079.71	27801.00	28457.98
XPV4_6	24	55099.94	62345.20	64279.46	63139.35	65005.98	66606.94
CA4_6	24	-1254.00	3092.00	6327.00	7474.88	11263.50	26694.00
INFV6_9	24	5529.00	8442.70	11121.98	10726.49	13542.19	20395.99
XPA6_9	24	24446.98	27345.20	28119.30	27665.49	28409.51	29049.99
XPA50_6_9	24	55099.94	62345.20	64279.46	63139.35	65005.98	66606.94
CA6_9	24	-5852.00	785.00	5833.50	5805.08	11001.50	15664.00

Note: Variable abbreviations are defined in Table 2.

Table 5
Sample sizes (N), minima, lower quartiles, medians, means, upper quartiles, and maxima of hydrologic variables derived for Lake Oahe, North and South Dakota

Variable[1]	N	Minimum	Lower Quartile	Median	Mean	Upper Quartile	Maximum
MG_WY	27	512.50	620.50	713.50	738.19	881.10	1075.30
CASUSP	26	-12545.00	-7087.00	661.50	1790.73	11930.00	21845.00
CASUSP2	25	-22136.00	-10876.00	2176.00	2784.16	10592.00	34994.00
CASUSU	26	-17350.00	-9778.00	261.50	1139.08	12153.00	26204.00
CASUSU2	25	-33614.00	-12760.00	4101.00	1344.88	12621.00	31305.00
INFV4_6	27	5950.00	6768.01	8005.00	8663.69	10872.99	15041.01
XSBINF4_6	27	0.00	42.50	143.00	79.52	313.70	505.80
XPA4_6	27	19957.00	25995.03	27812.97	27021.59	28552.02	28897.01
CA4_6	27	-10412.00	-2362.00	5626.00	4543.82	10172.00	18515.00
INFV6_9	27	6357.00	7355.00	8953.00	9480.00	12065.99	18373.99
XPA6_9	27	19598.00	26037.98	27489.00	26909.51	28796.98	29047.99
CA6_9	27	-14326.00	-10805.00	-6721.00	-6184.74	-3810.00	9906.00
XPA7_11	27	19327.00	25702.01	27210.03	26596.35	28208.02	28687.97
CA7_11	27	-20873.00	-13246.00	-10436.00	-9767.41	-7004.00	14626.00

[1] Variable abbreviations are defined in Table 2.

Table 6
Sample sizes (N), minima, l[illegible] quartiles, medians, means, upper quartiles, and maxima of hydrologic variab[illegible] derived for Lake Sharpe, South Dakota

Variable[1]	N	Minimum	Lower Quartile	Median	Mean	Upper Quartile	Maximum
MG_WY	28	456.90	623.04	670.82	691.80	786.84	1044.40
INFV4_6	27	4154.00	5920.99	7046.00	6862.63	7866.99	10725.01
XSBINF4_6	28	0.00	2.17	14.89	8.44	21.05	74.20
LFR4_6	27	1.91	2.74	3.30	3.22	3.73	4.94
INFV6_9	28	3439.00	9411.41	10241.08	10388.84	10388.84	16265.01
FR6_9	28	3.84	4.41	4.83	6.00	6.00	294.56

[1] Variable abbreviations are defined in Table 2.

Table 7
Sample sizes (N), minima, lower quartiles, medians, means, upper quartiles, and maxima of hydrologic variables derived for Lake Francis Case, South Dakota

Variable[1]	N	Minimum	Lower Quartile	Median	Mean	Upper Quartile	Maximum
MG_WY	28	503.50	656.07	691.55	722.13	820.01	1082.90
CASUSP	27	-2485.00	-290.00	525.00	667.96	1657.00	5126.00
CASUSP2	26	-2568.00	-403.00	1080.50	1363.04	2463.00	8055.00
CASUSU	27	-3669.00	-982.00	-89.00	82.93	1483.00	3067.00
CASUSU2	26	-4327.00	-1005.00	-21.50	238.85	1413.00	5538.00
INFV4_6	28	4921.00	6632.40	7579.49	7463.40	8578.48	11590.99
XSBINF4_6	28	0.00	38.71	70.87	48.50	86.35	135.00
XPA4_5	28	10134.01	10441.49	10511.50	10518.01	10614.49	10791.00
CA4_5	28	-2104.00	543.50	580.00	867.64	2164.50	6554.00
INFV6_9	28	8374.00	9906.00	10487.50	11424.71	12620.50	17104.00
XPA6_9	28	10005.00	10410.50	10472.50	10468.86	10575.00	10810.00
CA6_9	28	-6192.00	-3880.00	-2529.00	-2671.14	-1483.50	335.00

[1] Variable abbreviations are defined in Table 2.

Table 8
Sample sizes (N), minima, lower quartiles, medians, means, upper quartiles, and maxima of hydrologic variables derived for Lewis and Clark Lake, South Dakota

Variable[1]	N	Minimum	Lower Quartile	Median	Mean	Upper Quartile	Maximum
MG_WY	28	580.30	711.68	770.01	779.24	870.72	1121.20
INFV4_6	28	5586.99	7418.51	8018.53	7933.82	8800.38	11218.00
XSBINF4_6	28	38.60	67.10	81.40	85.78	113.89	195.70
FR4_6	28	11.54	15.28	17.00	17.05	18.73	23.83
INFV6_9	28	10070.01	11280.95	12192.49	12503.92	13703.94	18325.98
FR6_9	28	18.82	21.54	23.27	24.46	26.74	35.98

[1] Variable abbreviations are defined in Table 2.

Table 9
Distribution statistics for log-transformed catches of young-of-year fishes by reservoir, species, and gear[1]

Fort Peck northern pike in seines; Variable = log (number per haul + 1)			
N	17		
Mean	0.178985	Sum	3.042749
Std Dev	0.247881	Variance	0.061445
Skewness	2.508406	Kurtosis	5.905228
CV	138.4925	Std Mean	0.06012
Quantiles			
100% Max	0.939519	95%	0.939519
75% Q3	0.173186	90%	0.672098
50% Med	0.079181	10%	0.041393
25% Q1	0.041393	5%	0.041393
0% Min	0.041393		

Fort Peck sauger in seines; Variable = log (number per haul + 1)			
N	14		
Mean	0.141113	Sum	1.975576
Std Dev	0.062443	Variance	0.003899
Skewness	-0.20841	Kurtosis	-0.46756
CV	44.25036	Std Mean	0.016689
Quantiles			
100% Max	0.255273	95%	0.255273
75% Q3	0.173186	90%	0.20412
50% Med	0.159657	10%	0.041393
25% Q1	0.079181	5%	0.041393
0% Min	0.041393		

Fort Peck yellow perch in seines; Variable = log (number per haul + 1)			
N	17		
Mean	1.658385	Sum	28.19255
Std Dev	0.598484	Variance	0.358183
Skewness	-0.74726	Kurtosis	-0.81334
CV	36.08833	Std Mean	0.145154
Quantiles			
100% Max	2.355643	95%	2.355643
75% Q3	2.144574	90%	2.21906
50% Med	1.79588	10%	0.78533
25% Q1	1.089905	5%	0.462398
0% Min	0.462398		

Sakakawea walleye in gill nets; Variable = log (number per hour +1)			
N	19		
Mean	0.040194	Sum	0.763683
Std Dev	0.031005	Variance	0.000961
Skewness	1.148238	Kurtosis	0.432335
CV	77.13984	Std Mean	0.007113
Quantiles			
100% Max	0.112605	95%	0.112605
75% Q3	0.66699	90%	0.101059
50% Med	0.026125	10%	0.009451
25% Q1	0.017033	5%	0.008174
0% Min	0.008174		

(Sheet 1 of 7)

[1] Definitions of abbreviated variables are as follows: N = sample size; Std Dev = standard deviation; CV = coefficient of variation; Std Mean = standard error of the mean; Max = maximum; Q3 = 75th percentile; Med = median; Q1 = 25th percentile; Min = minimum.

Table 9 (Continued)

Sakakawea crappie in frame nets; Variable = log (number per hour + 1)			
N	19		
Mean	0.095631	Sum	1.816995
Std Dev	0.089531	Variance	0.008016
Skewness	1.266363	Kurtosis	0.96743
CV	93.62149	Std Mean	0.02054
Quantiles			
100% Max	0.31597	95%	0.31597
75% Q3	0.149219	90%	0.274158
50% Med	0.060698	10%	0.017033
25% Q1	0.021189	5%	0.004321
0% Min	0.004321		
Oahe, ND, walleye in gill nets; Variable = log (number per hour + 1)			
N	17		
Mean	0.026226	Sum	0.445847
Std Dev	0.041458	Variance	0.001719
Skewness	2.888644	Kurtosis	9.056593
CV	158.0769	Std Mean	0.010055
Quantiles			
100% Max	0.168055	95%	0.168055
75% Q3	0.02214	90%	0.073755
50% Med	0.010342	10%	0.002986
25% Q1	0.006124	5%	0.000738
0% Min	0.000738		
Oahe, ND, white bass in gill nets; Variable = log (number per hour + 1)			
N	17		
Mean	0.127136	Sum	2.161315
Std Dev	0.135155	Variance	0.018267
Skewness	1.178775	Kurtosis	0.866936
CV	106.3074	Std Mean	0.03278
Quantiles			
100% Max	0.466853	95%	0.466853
75% Q3	0.225361	90%	0.313572
50% Med	0.072654	10%	0
25% Q1	0.023499	5%	0
0% Min	0		
Oahe, ND, crappie in small frame nets; Variable = log (number per hour + 1)			
N	17		
Mean	0.280908	Sum	4.775437
Std Dev	0.290567	Variance	0.084429
Skewness	1.148339	Kurtosis	0.09985
CV	103.4384	Std Mean	0.070473
Quantiles			
100% Max	0.871666	95%	0.871666
75% Q3	0.312389	90%	0.841422
50% Med	0.183298	10%	0.01695
25% Q1	0.03153	5%	0.003719
0% Min	0.003719		

(Sheet 2 of 7)

Table 9 (Continued)

Oahe, ND, yellow perch in small frame nets; Variable = log (number per hour + 1)			
N	17		
Mean	0.182641	Sum	3.104894
Std Dev	0.261334	Variance	0.068296
Skewness	1.903691	Kurtosis	2.766081
CV	143.0864	Std Mean	0.063383
Quantiles			
100% Max	0.815936	95%	0.815936
75% Q3	0.234796	90%	0.815452
50% Med	0.042733	10%	0.004536
25% Q1	0.032498	5%	0.000651
0% Min	0.000651		
Oahe, SD, northern pike in seines; Variable = log (number per haul + 1)			
N	20		
Mean	0.027704	Sum	0.554082
Std Dev	0.054545	Variance	0.002975
Skewness	2.541252	Kurtosis	6.08148
CV	196.8832	Std Mean	0.012197
Quantiles			
100% Max	0.20412	95%	0.175124
75% Q3	0.020775	90%	0.112655
50% Med	0	10%	0
25% Q1	0	5%	0
0% Min	0		
Oahe, SD, walleye in seines; Variable = log (number per haul + 1)			
N	20		
Mean	0.153098	Sum	3.061968
Std Dev	0.19212	Variance	0.03691
Skewness	1.614917	Kurtosis	2.330558
CV	125.4878	Std Mean	0.042959
Quantiles			
100% Max	0.69897	95%	0.588046
75% Q3	0.190106	90%	0.454243
50% Med	0.096562	10%	0
25% Q1	0	5%	0
0% Min	0		
Oahe, SD, white bass in seines; Variable = log (number per haul + 1)			
N	20		
Mean	1.344825	Sum	26.89649
Std Dev	0.422464	Variance	0.178476
Skewness	0.337966	Kurtosis	-0.3869
CV	31.41404	Std Mean	0.094466
Quantiles			
100% Max	2.206826	95%	2.099247
75% Q3	1.607157	90%	1.98922
50% Med	1.30533	10%	0.757672
25% Q1	1.011832	5%	0.707487
0% Min	0.69897		

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Table 9 (Continued)

Oahe, SD, white crappie in seines; Variable = log (number per haul + 1)			
N	9		
Mean	0.262832	Sum	2.365488
Std Dev	0.472856	Variance	0.223592
Skewness	2.48612	Kurtosis	6.650386
CV	179.9079	Std Mean	0.157619
Quantiles			
100% Max	1.462398	95%	1.462398
75% Q3	0.30103	90%	1.462398
50% Med	0	10%	0
25% Q1	0	5%	0
0% Min	0		
Oahe, SD, yellow perch in seines; Variable = log (number per haul + 1)			
N	20		
Mean	1.437807	Sum	28.75615
Std Dev	0.716007	Variance	0.512666
Skewness	0.099228	Kurtosis	-0.9922
CV	49.79855	Std Mean	0.160104
Quantiles			
100% Max	2.76809	95%	2.630704
75% Q3	1.925718	90%	2.36455
50% Med	1.380091	10%	0.477121
25% Q1	0.80103	5%	0.477121
0% Min	0.477121		
Sharpe gizzard shad in seines; Variable = log (number per haul + 1)			
N	18		
Mean	2.321466	Sum	41.78639
Std Dev	0.459592	Variance	0.211224
Skewness	0.008068	Kurtosis	-1.09756
CV	19.79747	Std Mean	0.108327
Quantiles			
100% Max	3.131939	95%	3.131939
75% Q3	2.659916	90%	2.904174
50% Med	2.317543	10%	1.675778
25% Q1	1.965202	5%	1.61595
0% Min	1.61595		
Sharpe freshwater drum in seines; Variable = log (number per haul + 1)			
N	18		
Mean	0.420005	Sum	7.560098
Std Dev	0.336	Variance	0.112896
Skewness	0.351766	Kurtosis	-1.13338
CV	79.99886	Std Mean	0.079196
Quantiles			
100% Max	1.079181	95%	1.079181
75% Q3	0.69897	90%	0.845098
50% Med	0.406457	10%	0.041393
25% Q1	0.079181	5%	0
0% Min	0		

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Table 9 (Continued)

Sharpe walleye in seines; Variable = log (number per haul + 1)

N	18		
Mean	0.66360	Sum	11.94478
Std Dev	0.30619	Variance	0.093752
Skewness	1.26178	Kurtosis	2.540681
CV	46.14085	Std Mean	0.07217
Quantiles			
100% Max	1.531479	95%	1.531479
75% Q3	0.845098	90%	0.954243
50% Med	0.579633	10%	0.30103
25% Q1	0.477121	5%	0.278754
0% Min	0.278754		

Sharpe white bass in seines; Variable = log (number per haul + 1)

N	18		
Mean	0.633824	Sum	11.40884
Std Dev	0.502183	Variance	0.252187
Skewness	0.579233	Kurtosis	-0.99596
CV	79.23059	Std Mean	0.118366
Quantiles			
100% Max	1.544068	95%	1.544068
75% Q3	1.041393	90%	1.447158
50% Med	0.560287	10%	0.079181
25% Q1	0.146128	5%	0.079181
0% Min	0.079181		

Francis Case gizzard shad in seines; Variable = log (number per haul + 1)

N	22		
Mean	1.429021	Sum	31.43846
Std Dev	0.70904	Variance	0.502738
Skewness	0.007643	Kurtosis	-0.58758
CV	49.6172	Std Mean	0.151168
Quantiles			
100% Max	2.531479	95%	2.454845
75% Q3	1.907551	90%	2.424882
50% Med	1.331719	10%	0.795045
25% Q1	0.981229	5%	0.27277
0% Min	0.01536		

Francis Case walleye in gill nets; Variable = log (number per net night + 1)

N	10		
Mean	0.539595	Sum	5.395955
Std Dev	0.3296	Variance	0.108636
Skewness	-0.11496	Kurtosis	-0.73228
CV	61.08276	Std Mean	0.104229
Quantiles			
100% Max	0.995635	95%	2.3[illegible]216
75% Q3	0.748188	90%	2.267172
50% Med	0.504938	10%	0.931458
25% Q1	0.342423	5%	0.863561
0% Min	0		

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Table 9 (Continued)

Francis Case white bass in seines; Variable = log (number per haul + 1)			
N	21		
Mean	1.491915	Sum	31.33021
Std Dev	0.551972	Variance	0.304673
Skewness	0.150358	Kurtosis	-0.50528
CV	36.99754	Std Mean	0.12045
Quantiles			
100% Max	2.517196	95%	2.369216
75% Q3	1.83089	90%	2.267172
50% Med	1.407136	10%	0.931458
25% Q1	1.056486	5%	0.863561
0% Min	0.390228		
Francis Case white crappie in seines; Variable = log (number per haul + 1)			
N	21		
Mean	0.322826	Sum	6.779338
Std Dev	0.491308	Variance	0.241383
Skewness	1.755407	Kurtosis	2.185588
CV	152.1898	Std Mean	0.107212
Quantiles			
100% Max	1.63731	95%	1.380211
75% Q3	0.477121	90%	1.189041
50% Med	0.0306	10%	0
25% Q1	0	5%	0
0% Min	0		
Francis Case yellow perch in seines; Variable = log (number per haul +1)			
N	22		
Mean	1.08346	Sum	23.83612
Std Dev	0.52817	Variance	0.27896
Skewness	0.12191	Kurtosis	-0.23661
CV	48.74848	Std Mean	0.11260
Quantiles			
100% Max	2.05490	95%	2.032728
75% Q3	1.38806	90%	1.748188
50% Med	1.03984	10%	0.519566
25% Q1	0.69897	5%	0.374235
0% Min	0		
Lewis and Clark gizzard shad in seines; Variable = log (number per haul + 1)			
N	18		
Mean	1.968775	Sum	35.43794
Std Dev	0.613034	Variance	0.375811
Skewness	0.025618	Kurtosis	-0.89553
CV	31.13786	Std Mean	0.144494
Quantiles			
100% Max	2.941014	95%	2.941014
75% Q3	2.436163	90%	2.793092
50% Med	1.96901	10%	1.230449
25% Q1	1.477158	5%	0.819544
0% Min	0.819544		

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Table 9 (Concluded)

Lewis and Clark sauger in seines; Variable = log (number per haul + 1)			
N	18		
Mean	0.596059	Sum	10.72906
Std Dev	0.35612	Variance	0.126822
Skewness	0.888521	Kurtosis	1.108837
CV	59.74586	Std Mean	0.083938
Quantiles			
100% Max	1.491362	95%	1.491362
75% Q3	0.778151	90%	1.113943
50% Med	0.477121	10%	0.278754
25% Q1	0.30103	5%	0
0% Min	0		
Lewis and Clark yellow perch in seines; Variable = log (number per haul + 1)			
N	18		
Mean	0.612634	Sum	11.02741
Std Dev	0.428944	Variance	0.18399
Skewness	0.488682	Kurtosis	-0.27663
CV	70.01629	Std Mean	0.101103
Quantiles			
100% Max	1.556303	95%	1.556303
75% Q3	0.845098	90%	1.146128
50% Med	0.60206	10%	0
25% Q1	0.30103	5%	0
0% Min	0		

(Sheet 7 of 7)

Table 10
Regression statistics by reservoir, species, and gear[1]

Fort Peck Northern Pike in Seines; log (number/haul + 1)
Step 1 Variable CA6_9 Entered r-square = 0.34351906

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	1	0.33772084	0.33772084	7.85	0.0134
Error	15	0.64540026	0.04302668		
Total	16	0.98312110			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	0.14285371	0.05193558	0.32552992	7.57	0.0149
CA6_9	0.00004365	0.00001558	0.33772084	7.85	0.0134

Fort Peck Sauger in Seines; log (number/haul + 1)
Step 2 Variable CASUSP Entered R-square = 0.61910543

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	2	0.03138146	0.01569073	8.94	0.0049
Error	11	0.01930693	0.00175518		
Total	13	0.05068839			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	-13.24362802	3.17481270	0.03054206	17.40	0.0016
CASUSP	-0.00001168	0.00000448	0.01192039	6.79	0.0244
log(XPA6_9+1)	3.19689265	0.75848420	0.03118054	17.76	0.0014

Fort Peck Yellow Perch in Seines; log (number/haul + 1)
Step 2 Variable CASUSU2 Entered R-square = 0.72756140

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	2	4.16959679	2.08479840	18.69	0.0001
Error	14	1.56132406	0.11152315		
Total	16	5.73092085			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	-172.51437506	30.67724333	3.52681706	31.62	0.0001
CASUSU2	-0.00006448	0.00002136	1.01601045	9.11	0.0092
log(XPA6_9+1)	41.64612989	7.33268038	3.59740062	32.26	0.0001

Sakakawea Walleye in Gill Nets; log (number/hr)
Step 1 Variable CA4_6 Entered r-square = 0.57641432 C(p) = 8.37646892

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	1	0.00737146	0.00737146	23.13	0.0002
Error	17	0.00541702	0.00031865		
Total	18	0.01278848			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	0.00760743	0.00606308	0.00050165	1.57	0.2266
CA4_6	0.00000308	0.00000064	0.00737146	23.13	0.0002

(Sheet 1 of 8)

[1]Independent variable abbreviations are in Table 2 and sample statistics are in Tables 3-8. Other abbreviations include R-square = coefficient of determination (multiple regression); r-square = coefficient of determination (single-variable regression); DF = degrees of freedom; F = F statistic; Prob>F = equation probability.

Table 10 (Continued)

Sakakawea White Crappie in Frame Nets; log (number/hr)
Step 4 Variable LINFV4_6 Removed R-square = 0.62382038
Variable LMG_WY Entered

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	3	0.09000846	0.03000282	8.29	0.0017
Error	15	0.05427740	0.00361849		
Total	18	0.14428586			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	-0.14042899	0.58533530	0.00020827	0.06	0.8136
log(MG_WY+1)	-1.54484945	0.64183917	0.02096272	5.79	0.0294
log(INFV6_9+1)	1.14759144	0.48833657	0.01998315	5.52	0.0329
CASUSU	0.00000888	0.00000267	0.03990683	11.03	0.0047

Oahe, ND, Walleye in Gill Nets; log (number/hr)
Step 4 Variable LMG_WY Removed R-square = 0.71358759
Variable LINFV6_9 Entered

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	3	0.01962360	0.00654120	10.80	0.0008
Error	13	0.00787632	0.00060587		
Total	16	0.02749991			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	-1.03527621	0.34446804	0.00547261	9.03	0.0101
log(INFV6_9+1)	0.25772691	0.08401390	0.00570160	9.41	0.0090
CA6_9	-0.00000648	0.00000210	0.00579732	9.57	0.0086
CASUSP	0.00000389	0.00000080	0.01427635	23.56	0.0003

Oahe, ND, White Bass in Gill Nets; log (number/hr)
Step 3 Variable CA6_9 Entered R-square = 0.64781514

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	3	0.18933719	0.06311240	7.97	0.0029
Error	13	0.10293321	0.00791794		
Total	16	0.29227040			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	-1.90059872	0.97460668	0.03011163	3.80	0.0731
log(INFV4_6+1)	0.50238066	0.24223918	0.03405565	4.30	0.0585
CA6_9	-0.00000973	0.00000568	0.02322475	2.93	0.1105
CASUSP	0.00001085	0.00000297	0.10586342	13.37	0.0029

Oahe, ND, White Crappie in Frame Nets; log (number/hr)
Step 5 Variable CASUSP Removed R-square = 0.52495658
Variable CASUSU Entered

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	3	0.70914581	0.23638194	4.79	0.0184
Error	13	0.64171985	0.04936307		
Total	16	1.35086565			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	-5.96337033	3.03804471	0.19019424	3.85	0.0714
log(MG_WY+1)	2.11101896	1.03558236	0.20512429	4.16	0.0624
CA6_9	-0.00003262	0.00001687	0.18465847	3.74	0.0752
CASUSU	0.00001323	0.00000639	0.21162636	4.29	0.0589

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Table 10 (Continued)

Oahe, ND, Yellow Perch in Frame Nets; log (number/hr)
Step 1 Variable CASUSU Entered r-square = 0.38701550

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	1	0.42290301	0.42290301	9.47	0.0077
Error	15	0.66982584	0.04465506		
Total	16	1.09272885			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	0.19800134	0.05149448	0.66021514	14.78	0.0016
CASUSU	0.00001363	0.00000443	0.42290301	9.47	0.0077

Oahe, SD, Northern Pike in Seines; log (number/haul+1)
Step 6 Variable LMG_WY Removed R-square = 0.64852268
Variable LINFV6_9 Entered

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	4	0.01541332	0.00385333	6.46	0.0037
Error	14	0.00835350	0.00059668		
Total	18	0.02376682			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	-0.92134731	0.23523221	0.00915363	15.34	0.0015
log(INFV6_9+1)	0.22892196	0.05812956	0.00925382	15.51	0.0015
CA6_9	-0.00000317	0.00000115	0.00454586	7.62	0.0153
CASUSU2	-0.00000281	0.00000126	0.00294681	4.94	0.0433
CASUSP2	0.00000393	0.00000139	0.00477238	8.00	0.0134

Oahe, SD, Walleye in Seines; log (number/haul+1)
Step 2 Variable LINFV4_6 Entered R-square = 0.23406153

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	2	0.14506745	0.07253373	2.44	0.1185
Error	16	0.47471595	0.02966975		
Total	18	0.61978340			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	-2.35186019	1.39860245	0.08389736	2.83	0.1121
log(INFV4_6+1)	0.63629816	0.35569630	0.09494596	3.20	0.0926
CASUSU2	-0.00000446	0.00000245	0.09873120	3.33	0.0869

Oahe, SD, White Bass in Seines; log (number/haul+1)
Step 4 Variable CA6_9 Removed R-square = 0.69067754
Variable CASUSU Entered

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	3	2.24654767	0.74884922	11.16	0.0004
Error	15	1.00612458	0.06707497		
Total	18	3.25267225			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	1.27989249	0.07129923	21.61412998	322.24	0.0001
CA4_6	0.00002130	0.00000927	0.35466639	5.29	0.0363
CASUSU	0.00003308	0.00000874	0.96073432	14.32	0.0018
CASUSU2	-0.00001831	0.00000500	0.89756816	13.38	0.0023

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Table 10 (Continued)

Oahe, SD, White Crappie in Seines; log (number/haul+1)
Step 2 Variable CA6_9 Entered R-square = 0.66113180

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	2	1.18259234	0.59129617	5.85	0.0389
Error	6	0.60614681	0.10102447		
Total	8	1.78873915			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	-0.30236343	0.21707221	0.19600928	1.94	0.2131
CA6_9	-0.00008683	0.00002873	0.92288906	9.14	0.0233
CASUSP	0.00005184	0.00001603	1.05654080	10.46	0.0178

Oahe, SD, Yellow Perch in Seines; log (number/haul+1)
Step 1 Variable LMG_WY Entered r-square = 0.42090188

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	1	3.96568961	3.96568961	12.36	0.0027
Error	17	5.45619666	0.32095274		
Total	18	9.42188627			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	-13.30048861	4.18661985	3.23928551	10.09	0.0055
log(MG_WY+1)	5.12792536	1.45882394	3.96568961	12.36	0.0027

Sharpe Gizzard Shad in Seines; log (number/haul+1)
Step 1 Variable LFR4_6 Entered r-square = 0.46707387

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	1	1.67717589	1.67717589	14.02	0.0018
Error	16	1.91363918	0.11960245		
Total	17	3.59081507			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	4.77853761	0.66118699	6.24714369	52.23	0.0001
log(FR4_6+1)	-3.94488441	1.05345268	1.67717589	14.02	0.0018

Sharpe Walleye in Seines; log (number/haul+1)
Step 1 Variable LMG_WY Entered r-square = 0.47702210

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	1	0.58869534	0.58869534	6.38	0.0394
Error	7	0.64540962	0.09220137		
Total	8	1.23410495			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	17.88154868	6.78859063	0.63971776	6.94	0.0337
log(MG_WY+1)	-6.11484906	2.41996531	0.58869534	6.38	0.0394

Table 10 (Continued)

Sakakawea White Crappie in Frame Nets; log (number/hr)
Step 4 Variable LINFV4_6 Removed R-square = 0.62382038
Variable LMV_WY Entered

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	3	0.09000846	0.03000282	8.29	0.0017
Error	15	0.05427740	0.00361849		
Total	18	0.14428586			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	-0.14042899	0.58533530	0.00020827	0.06	0.8136
log(MG_WY+1)	-1.54484945	0.64183917	0.02096272	5.79	0.0294
log(INFV6_9+1)	1.14759144	0.48833657	0.01998315	5.52	0.0329
CASUSU	0.00000888	0.00000267	0.03990683	11.03	0.0047

Oahe, ND, Walleye in Gill Nets; log (number/hr)
Step 4 Variable LMG_WY Removed R-square = 0.71358759
Variable LINFV6_9 Entered

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	3	0.01962360	0.00654120	10.80	0.0008
Error	13	0.00787632	0.00060587		
Total	16	0.02749991			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	-1.03527621	0.34446804	0.00547261	9.03	0.0101
log(INFV6_9+1)	0.25772691	0.08401390	0.00570160	9.41	0.0090
CA6_9	-0.00000648	0.00000210	0.00579732	9.57	0.0086
CASUSP	0.00000389	0.00000080	0.01427635	23.56	0.0003

Oahe, ND, White Bass in Gill Nets; log (number/hr)
Step 3 Variable CA6_9 Entered R-square = 0.64781514

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	3	0.18933719	0.06311240	7.97	0.0029
Error	13	0.10293321	0.00791794		
Total	16	0.29227040			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	-1.90059872	0.97460668	0.03011163	3.80	0.0731
log(INFV4_6+1)	0.50238066	0.24223918	0.03405565	4.30	0.0585
CA6_9	-0.00000973	0.00000568	0.02322475	2.92	0.1105
CASUSP	0.00001085	0.00000297	0.10586342	13.37	0.0029

Oahe, ND, White Crappie in Frame Nets; log (number/hr)
Step 5 Variable CASUSP Removed R-square = 0.52495658
Variable CASUSU Entered

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	3	0.70914581	0.23638194	4.79	0.0184
Error	13	0.64171985	0.04936307		
Total	16	1.35086565			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	-5.96337033	3.03804471	0.19019424	3.85	0.0714
log(MG_WY+1)	2.11101896	1.03558236	0.20512429	4.16	0.0624
CA6_9	0.00003262	0.00001687	0.18465847	3.74	0.0752
CASUSU	0.00001323	0.00000639	0.21162636	4.29	0.0589

(Sheet 5 of 8)

Table 10 (Continued)

Sharpe White Bass in Seines; log (number/haul+1)
Step 1 Variable LFR4_6 Entered r-square = 0.33342278

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	1	1.42944552	1.42944552	8.00	0.0121
Error	16	2.85774063	0.17860879		
Total	17	4.28718615			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	2.90218571	0.80798942	2.30431516	12.90	0.0024
log(FR4_6+1)	-3.64190641	1.28734927	1.42944552	8.00	0.0121

Sharpe Freshwater Drum in Seines; log (number/haul+1)
Step 1 Variable LINFV4_6 Entered r-square = 0.53057930

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	1	1.01830204	1.01830204	18.08	0.0006
Error	16	0.90092480	0.05630780		
Total	17	1.91922683			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	9.44482884	2.12292895	1.11451475	19.79	0.0004
log(INFV4_6+1)	-2.35464544	0.55369614	1.01830204	18.08	0.0006

Francis Case Gizzard Shad in Seines; log (number/haul+1)
Step 1 Variable CA6_9 Entered r-square = 0.41412201

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	1	1.11271293	1.11271293	4.95	0.0615
Error	7	1.57420759	0.22488680		
Total	8	2.68692052			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	2.56307236	0.31066960	15.30693327	68.07	0.0001
CA6_9	0.00032631	0.00014670	1.11271293	4.95	0.0615

Francis Case Walleye in Gill Nets; log (number/net night)
Step 2 Variable LINFV4_6 Entered R-square = 0.93908113

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	2	0.61435592	0.3071796	46.25	0.0002
Error	6	0.03985371	0.00664229		
Total	8	0.65420963			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	-12.75772262	2.08084273	0.24968092	37.59	0.0009
log(INFV4_6+1)	3.22437950	0.53245589	0.24358054	36.67	0.0009
log(SBINF46+1)	0.66742812	0.07126818	0.58255271	87.70	0.0001

(Sheet 6 of 8)

Table 10 (Continued)

Francis Case White Bass in Seines; log (number/haul+1)
Step 1 Variable CA4_5 Entered r-square = 0.46677001

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	1	0.89064810	0.89064810	6.13	0.0425
Error	7	1.01746101	0.14535157		
Total	8	1.90810911			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	1.50305607	0.18437538	9.65971309	66.46	0.0001
CA4_5	0.00026772	0.00010815	0.89064810	6.13	0.0425

Francis Case White Crappie in Seines; log (number/haul+1)
Step 1 Variable CASUSP2 Entered r-square = 0.39504611

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	1	1.90714949	1.90714949	12.41	0.0023
Error	19	2.92051352	0.15371124		
Total	20	4.82766301			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	0.14198927	0.09977605	0.31128918	2.03	0.1709
CASUSP2	0.00012352	0.00003507	1.90714949	12.41	0.0023

Francis Case Yellow Perch in Seines; log (number/haul+1)
Step 1 Variable CA4_5 Entered r-square = 0.85184871

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	1	0.94177749	0.94177749	40.28	0.0004
Error	7	0.16379147	0.02339878		
Total	8	1.10556896			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	0.78560036	0.07397580	2.63886524	112.78	0.0001
CA4_5	0.00027530	0.00004339	0.94177749	40.25	0.0004

Lewis and Clark Gizzard Shad in Seines; log (number/haul+1)
Step 2 Variable LFR4_6 Entered R-square = 0.28563806 C(p) = 4.79250172

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	2	1.82488060	0.91244030	3.00	0.0802
Error	15	4.56390599	0.30426040		
Total	17	6.38878659			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	9.55360822	3.41755804	2.37765309	7.81	0.0136
LSBINF46	-2.23951226	0.96401494	1.64204400	5.40	0.0346
LFR4_6	-2.55878867	1.93304204	0.53312822	1.75	0.2054

Table 10 (Concluded)

Lewis and Clark Yellow Perch in Seines; log (number/haul+1)
Step 2 Variable LINFV4_6 Entered R-square = 0.32665666

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	2	1.02174163	0.51087081	3.64	0.0515
Error	15	2.10613467	0.14040898		
Total	17	3.12787630			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	8.00092271	5.69663642	0.27697338	1.97	0.1805
log(INFV4_6+1)	-0.99428531	1.32519435	0.07904197	0.56	0.4647
log(SBINF46+1)	-1.79395113	0.66518762	1.02123992	7.26	0.0166

Lewis and Clark Sauger in Seines; log (number/haul+1)
Step 2 Variable LFR6_9 Entered R-square = 0.49603852

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	2	1.06944426	0.53472213	7.38	0.0059
Error	15	1.08652591	0.07243506		
Total	17	2.15597017			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEPT	7.19505456	1.86541787	1.07761778	14.88	0.0016
LSBINF46	-1.62353292	0.46797126	0.87183173	12.04	0.0034
LFR6_9	-2.45795286	1.02712074	0.41481355	5.73	0.0302

(Sheet 8 of 8)

Table 11
Percent of years, under the large-seasonal-drawdown alternative, in which the value of an independent variable was 1, 10, 20, 30, 50, or 100 percent outside the range of the original data used to derive regression equations

Reservoir	Hydrologic Variable	> 1%	> 10%	> 20%	> 30%	> 50%	> 100%
Francis Case	CASUSP2	0.0	0.0	0.0	0.0	0.0	0.0
	SBINF	2.2	2.2	2.2	1.1	0.0	0.0
	CA4_5	1.1	1.1	1.1	1.1	1.1	1.1
	INFV4_6	32.3	25.8	16.1	10.8	0.0	0.0
	CA6_9	1.1	0.0	0.0	0.0	0.0	0.0
Fort Peck	CASUSP	20.7	16.3	12.0	12.0	9.8	4.3
	CASUSU2	20.9	17.6	13.2	12.1	7.7	2.2
	CA6_9	21.5	16.1	10.8	9.7	5.4	1.1
	XPA6_9	9.7	3.2	0.0	0.0	0.0	0.0
Lewis and Clark	SBINF	1.1	1.1	0.0	0.0	0.0	0.0
	INFV4_6	44.1	33.3	23.7	16.1	0.0	0.0
	FR4_6	59.1	43.0	34.4	28.0	10.8	0.0
	FR6_9	0.0	0.0	0.0	0.0	0.0	0.0
Oahe	MG_WY	3.2	1.1	0.0	0.0	0.0	0.0
	CASUSP	9.8	7.6	3.3	2.2	0.0	0.0
	CASUSU	7.6	5.4	3.3	3.3	1.1	0.0
	CASUSP2	3.3	3.3	1.1	0.0	0.0	0.0
	CASUSU2	4.4	2.2	1.1	1.1	0.0	0.0
	CA4_6	28.0	23.7	23.7	21.5	12.9	7.5
	INFV4_6	18.3	11.8	4.3	0.0	0.0	0.0
	CA6_9	11.8	9.7	5.4	3.2	1.1	1.1
	INFV6_9	0.0	0.0	0.0	0.0	0.0	0.0
Sakakawea	MG_WY	0.0	0.0	0.0	0.0	0.0	0.0
	CASUSU	21.7	18.5	10.9	9.8	6.5	2.2
	CA4_6	23.7	22.6	21.5	21.5	19.4	19.4
	INFV6_9	0.0	0.0	0.0	0.0	0.0	0.0
Sharpe	MG_WY	5.4	4.3	2.2	0.0	0.0	0.0
	INFV4_6	33.3	28.0	20.4	14.0	0.0	0.0
	FR4_6	35.5	30.1	22.6	15.1	1.1	0.0

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13. ABSTRACT *(Maximum 200 words)*

This report describes a method for predicting impacts of system-operating alternatives on fish reproduction in six Missouri River reservoirs (Fort Peck, Sakakawea, Oahe, Sharpe, Francis Case, and Lewis and Clark). Effects of seasonal or annual variations in reservoir hydrology on catches of young-of-year (YOY) fish in summer were quantified using correlation and regression analyses. Software was developed that predicts YOY catch and calculates a fish reproduction index (RI) for every possible year in the 93-year period of record (1898-1990) and any operational alternative. The method allows users to evaluate operational alternatives by comparing results from a long chronology of predicted indices. Small sample sizes and poor correlations between YOY fish catch and most fish stocking variables kept researchers from using stocking variables as covariates in regression analyses. Despite data limitations, the number of fingerling walleye stocked apparently is a legitimate covariate. The YOY walleye catch in Lake Sakakawea was adjusted to include only nonstocked YOY as a dependent variable. This adjustment resulted in a much stronger relation between YOY catch and change in area from April through June than when catch consisted of both stocked and naturally produced walleye. Correlation of YOY catch with weather variables yielded few consistent or useful results, and weather variables were not used in regression analyses. Correlation and regression analyses using hydrologic variables derived from daily data provided little or no improvement in predictive capability over variables derived from end-of-month data. Many highly significant

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13. **(Concluded).**

relations were found by regressing the geometric mean catch of YOY fishes on hydrologic variables derived from monthly data. Four system-operating alternatives were evaluated with an integrated model that pooled and postprocessed predictions for all reservoirs and indicator species. Alternatives differed mainly in minimum reservoir elevations in the four largest reservoirs and in inflows to the two run-of-river reservoirs during drought. Two environmental alternatives allowed for seasonal variation in water-level or hydrologic patterns among years. These alternatives, which provided a year of high water to one of the three largest reservoirs on a rotating basis, produced similar reproductive indices in most years. However, the alternative allowing the greatest summer drawdown produced six exceptionally high RI values and yielded more years with above-average indices than the alternative which limited drawdown. These results are significant because a strong year class of fish can persist for about 5 to 8 years, and sport fishes may dominate the catch of anglers for 3 to 5 years. Alternatives that limit annual drawdown are desirable only for severe drought periods when the fish reproduction and reservoir fisheries are both adversely affected by low water. The integrated model depends upon predicted hydrology from 1898 to 1990 to calculate independent variables, so values of some variables were outside the range of data used to derive regression equations. Extrapolation beyond the original data is not a serious problem for the integrated model because predictions for every reservoir and species were standardized to values between zero and one. Consequently, a prediction from a single equation cannot overly bias the composite annual estimate of the RI. Also, the integrated model was designed solely to compare alternatives, not to make quantitative predictions. Extrapolation is of concern for users making predictions of YOY catch. In these cases, input data should be screened, or users must assume that relations are consistent over a wider range of values of independent variables than ever observed.